LEVEL II MOST Project -2-

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(6) SIMULATION OF SEA SPECTRA IN THE NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER CARRIAGE II TEST FACILITY

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ABSTRACT

To model full-scale oceanographic conditions, the wavemaker for the 51-foot-wide deep basin at the Naval Ship Research and Development Center was modified to generate random waves having specific, spectral characteristics. The results of initial attempts to generate such wave spectra are reported, including calibration of the wavemaker unit and spatial studies to determine the variation in wave spectra with distance from wavemaker.

ADMINISTRATIVE INFORMATION

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INTRODUCTION

When testing models in irregular waves, a prescribed amount of data must be obtained to insure a certain level of statistical reliability. Tests in the Seakeeping Facility (MASK) must be repeated many times in order to accumulate the required amounts of test data, particularly for tests at high model speeds. This problem does not exist at zero or very low model speeds, but other considerations such as wave reflection become troublesome.

A factor governing the number of test runs that have to be made is the duration of an individual run. This in turn, depends upon the speed of the model and the test length of the facility. In the Seakeeping Facility, which is 360-feet long, it is sometimes necessary to make as many as 20 passes or runs to accumulate sufficient quantities of test data. This procedure is, unfortunately, time consuming and not too efficient.

The 51-foot-wide deep basin offers approximately 1500 feet of test-run length. Although tests in this facility are limited to head and following wave conditions, it is possible with this length, to reduce the number of test runs. Consequently, the pneumatic wavemaker in the deep basin was modified to generate irregular waves. Previously, the wavemaker had been limited to regular wave generation.

The purpose of this report is to present the results of an initial attempt to provide control input programs for the generation of specific model sea conditions in the deep basin. Also, the results of spatial studies showing the variation of various wave spectra with distance from the wavemaker are presented.

DESCRIPTION OF WAVEMAKER

A detailed description of the wavemaker is given by Brownell in Reference 1.* It consists of an inverted U-shaped dome that extends several feet above the free surface. The side that is toward the direction of wave propagation is terminated at some finite depth below the free surface; the other side extends to the bottom of the basin. The pressure on the free surface inside of the dome is varied by blowing air in or out of the dome. This air is supplied by a centrifugal blower and is controlled by a flapper-valve mechanism. The energy thus imparted to the free surface in the dome is propagated under the lip and away from the dome in the form of a surface wave. A sketch of the system is shown in Figure 1.

Recently, the wavemaker was modified to generate irregular or random waves. This modification consisted of replacing the original valve actuating motor and crankshaft with an electrical servo system. The system is designed to follow a position signal provided by either a magnetic tape playback or some other suitable source of analog voltage. Specifications for the system required that the valve servo system duplicate the response characteristic of the hydraulic actuators in the MASK facility. The system actually requires, at a minimum, a linear response characteristic over full-valve amplitude ranging from 0 to 1.2 cps. It is also desirable, but not necessary, that the phase factor vary linearly (if at all) with frequency.

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*References are listed on page 9.

TECHNIQUE OF PROGRAMMING

The technique used to prepare random wave programs consists of passing a "white noise" signal having Gaussian properties through a filter that shapes the output spectrum of the signal in conformity with the shape of the desired wave spectrum. Characteristics of the wavemaker system are compensated by passing this signal in through another filter with the inverse frequency response of the wavemaker system. In this approach, the wavemaker system is considered to be linear, and the frequency response is obtained by any of the usual methods. A detailed description of this technique is described in Reference 2.

The wave spectral shape desired is the form proposed by Pierson and Moskowitz;[3] it is given by

$$S(\omega) = 8.10 \times 10^{-3} \frac{g^2}{\omega^5} e^{-0.74\left(\frac{\omega_0}{\omega}\right)^4}$$

where g is acceleration due to gravity, and $\omega_0 = g/v$ where v is the wind velocity. In dimensionless form the spectrum is given by

$$\bar{S}(\omega) = S(\omega) \frac{\omega_0^5}{g^2} = \frac{8.10 \times 10^{-3}}{\left(\frac{\omega}{\omega_0}\right)^5} e^{-0.74\left(\frac{\omega_0}{\omega}\right)^4}$$

A plot of this spectrum is presented in Figure 2.

An advantage of this nondimensional spectral form is that the rms value of the spectrum is proportional to the square of the frequency at which the peak power occurs. This was not the case for some spectral forms used previously, and the wave generation process was complicated by the requirement of different rms values for spectra with the same peak frequency but with different model scale ratios. The relationship between the rms value and frequency of peak power for the Moskowitz spectrum is

$$\sigma = \frac{\text{[illegible]}}{f^2} \quad ; \quad \omega = 2\pi f$$

A plot of this relationship is shown in Figure 3 along with a nomogram that gives model rms values for various full-scale sea conditions and model-scale ratios.

TEST PROCEDURE AND RESULTS

GENERAL

Because the deep basin was required for an urgent purpose, it was decided for the initial studies to use random wave tape programs originally prepared for the wavemakers in the MASK facility. These wavemaker units are physically similar to the one in the deep basin except for the actuators, which are hydraulic in the MASK. The wavemaker door opening in the deep basin was modified to correspond to a 3-foot door opening used in the MASK facility when generating irregular waves.

The test program was divided into the following four parts.

1. Determination of frequency response characteristics of the wavemaker system by regular wave generation;

2. Calibration of random wave programs, i.e., determining for several random-wave programs the variation of spectrum rms values with blower speed in rpm;

3. Spatial studies, i.e., investigation of the variation of power spectrum with distance from wavemaker; and

4. Special programming.

The special programming concerns an attempt to compensate for the differences in velocity of various wave components that affect the initial phases of wave generation at large distances from the wavemakers.

WAVEMAKER RESPONSE CHARACTERISTICS

The results of the studies of the wavemaker frequency responses are shown in Figures 4 and 5. Figure 4 shows the variation of wave height (double amplitude) with frequencies for blower speeds of 400, 500, and 700 rpm at full-valve stroke. Also shown is the wave height for 500 rpm at half stroke. These data were obtained with a lip setting 22 inches below the free surface; see Figure 1. The lip was raised 4 inches to a new setting of 18 inches below the free surface, and data were obtained for blower speeds of 400, 500, and 650 rpm at full-valve stroke. These data are shown in Figure 5. The results of this study verify that the response characteristics of the wavemaker system are grossly linear with valve stroke and that the shape of the response curve (normalized) is about the same for all blower speeds.

CALIBRATION OF RANDOM WAVE PROGRAMS

The random wave programs evaluated during these tests were designed to produce spectra in the MASK facility having specific peak frequencies. Four of these programs representing spectra of different intensities were selected for evaluation and calibration in the deep basin. Table 1 shows the peak frequency associated with each of these programs.

TABLE 1

Peak Frequencies

Program	Peak Frequency in cps
1	0.350
2	0.415
3	0.485
4	0.575

Each program was run for approximately 20 minutes at several values of blower speed in rpm, and wave height measurements were obtained 200 feet away from the wavemaker.

The results are presented in Figures 6 through 9, which show wave spectra for the various wave programs and blower speeds. A comparison of the spectra from Program 1 in Figure 6, having a comparable Moskowitz or Newmann Spectrum, reveals that the program spectrum is deficient in energy at the higher frequencies. Several possible causes, all a matter of conjecture, are as follows:

1. The input program is deficient in high-frequency content; conversely the program is rich in low-frequency content.

2. The wavemaker system is amplitude saturated at the higher frequencies.

3. Some other unknown nonlinearity of the wavemaker system.

The speculation that some sort of saturation is taking place seems to be borne out by the results obtained with the other programs. An increase in the peak frequency of the program spectra attenuated the low frequency and the wave spectras as expected, but it did not increase the power at the high frequencies. For example, the results of Program 4 at a blower speed of 700 rpm, shown in Figure 9, do not indicate any more spectral energy at frequencies greater than 0.45 cps than Program 1 at the same blower speed. The power of the input signal at these frequencies was much greater for Program 4 than it was for Program 1.

It is obviously desirable to increase the efficiency of wave generation at the higher frequencies. This may be accomplished by changing the dome configuration to a 2-foot opening; see Figure 1. Also, some improvement in high-frequency wave generation may be obtained by raising the lip. The lip was raised for the remainder of this investigation in an attempt to increase the high-frequency content during the spatial studies.

SPATIAL STUDIES

The spatial studies consisted of measuring and comparing wave spectra generated by various programs 200, 450, 700, 950, 1200, and 1450 feet from the wavemaker. Since there were only two platforms from which to take measurements (portable bridge and test carriage); the measurements were made in pairs (200 and 450, 700 and 950, 1200 and 1450 feet from wavemaker), and the programs were repeated several times.

The programs selected for these studies were those required for an impending model test program. Nevertheless, they adequately define the spatial characteristics of the basin. As shown in Figures 10 through 12, the variation of the wave spectra with basin length does not appear to be very significant. The variation of the rms values with basin length is of the same order as instrumentation accuracy with the exception of measurements obtained 450 feet from the wavemaker. These measurements (450 feet from wavemaker) seem to be much lower than those obtained at the other locations. It is possible that these spectra are in error; however, no malfunction of the equipment was noticed at the time of the measurements.

SPECIAL PROGRAMMING

When initiating a wave program, some finite time will elapse before the waves travel the length of the basin. Since long waves travel faster than short waves, they will arrive at a particular station first and homogeneous wave conditions will not exist over the span of the basin until the shorter waves catch up. Afterwards, the wave conditions at any point in the basin remain stationary until the wavemaker is stopped.

Time may be saved by compensating the initial phases of the wave programs so that stationary wave conditions are established over the entire test length of the basin at approximately the same time the initial disturbances reach the end of the basin. This is accomplished by delaying the generation of the longer, faster travelling waves to give the shorter waves a head start. In practice, this is achieved by passing the input program signal through a high-band-pass filter with a variable cutoff frequency. The cutoff frequency is continuously lowered allowing for a gradual increase in low-frequency waves. The rate at which the cutoff frequency is varied can be determined from the following considerations.

The surface elevation at two points, separated by a distance X in the direction of wave travel, can be related through a convolution-type integral. The weighting function $w(t)$ required for this convolution is approximately equal to

$$W(\tau) = \sqrt{g/\pi X}\ \cos\left(\frac{g\tau^2}{4X} - \frac{\pi}{4}\right)$$

for large values of t.

This function behaves like a time-delay network, retarding each component in proportion to its frequency. To have all wave components arrive at a particular point simultaneously requires that the cutoff frequency vary at the same rate as the apparent frequency $\omega(t)$ of the weighting function, i.e.,

$$\omega = \frac{d}{d\tau}\left(\frac{g\tau^2}{4X} - \frac{\pi}{4}\right)$$

$$\frac{d\,\omega(\tau)}{d\tau} = \frac{g}{2X}$$

A wave program was altered in the preceding manner so that stationary wave condition would exist simultaneously with the arrival of the wave front 1200 feet from the wavemaker. This is the usual starting point for a test in head waves. Figure 13 compares the spectra obtained by analyzing the first 5 minutes of data obtained from a program with and without the compensation. Also included is a 10-minute analysis of a subsequent portion of the program that serves as a reference for the comparison. The results indicate that the procedure does work. No unexpected phenomena occurred with either the compensated or uncompensated programs. No compensation is required if several minutes are allowed to elapse after the waves reach the carriage.

RECOMMENDATIONS

It is recommended that the wavemaker be modified so that a 2-foot dome opening can be obtained. The present 3-foot opening results in wave spectra that are deficient in high-frequency energy content. A 2-foot dome opening will increase the efficiency of high-frequency wave generation, hopefully, without too much loss of low-frequency wave generation.

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2. Davis, M. C., "Simulation of a Long-Crested Gaussian Seaway," David Taylor Model Basin Report 1755, (Apr 1964).

3. Pierson, W. V. and Moskowitz, L., "A Proposed Spectral Form of Fully Developed Wind Seas Based on Simularity Theory of S. A. Kitaigorodskii," Journal of Geographical Research, Vol. 69, No. 24, (1964).

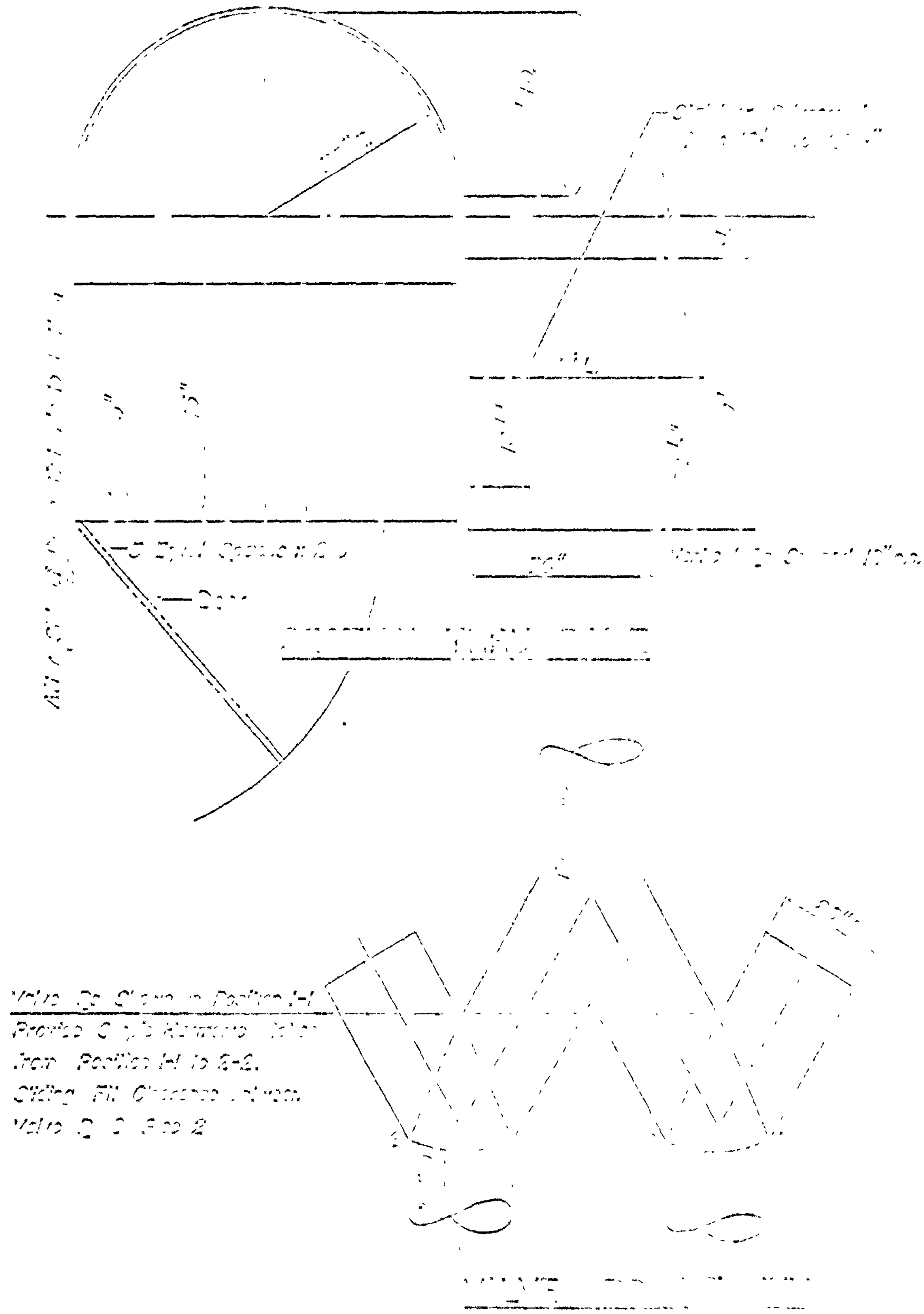


Figure 1 - Sketch of Wavemaker System.

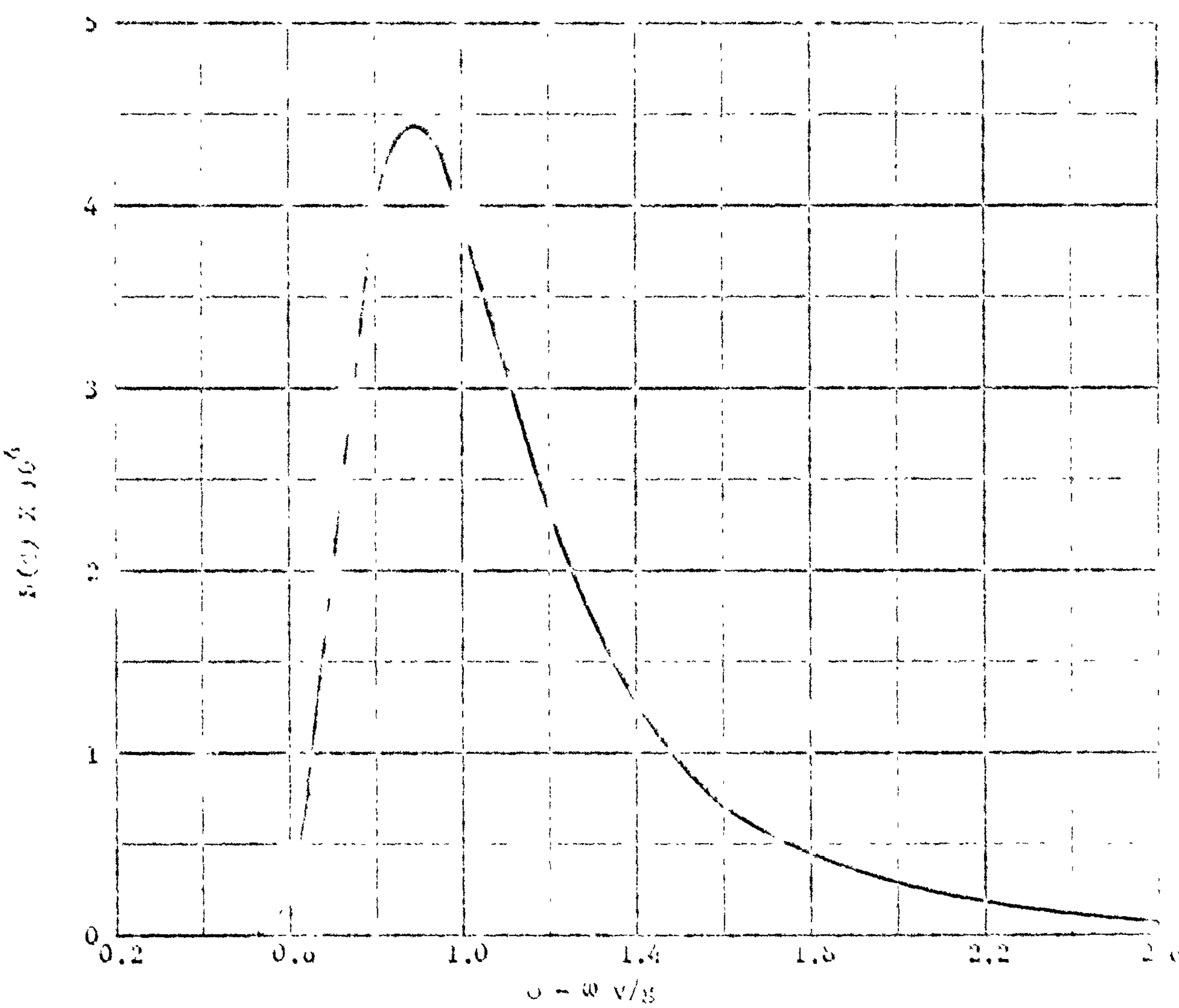


Figure 2 - Pierson-Moskowitz Spectral Form.

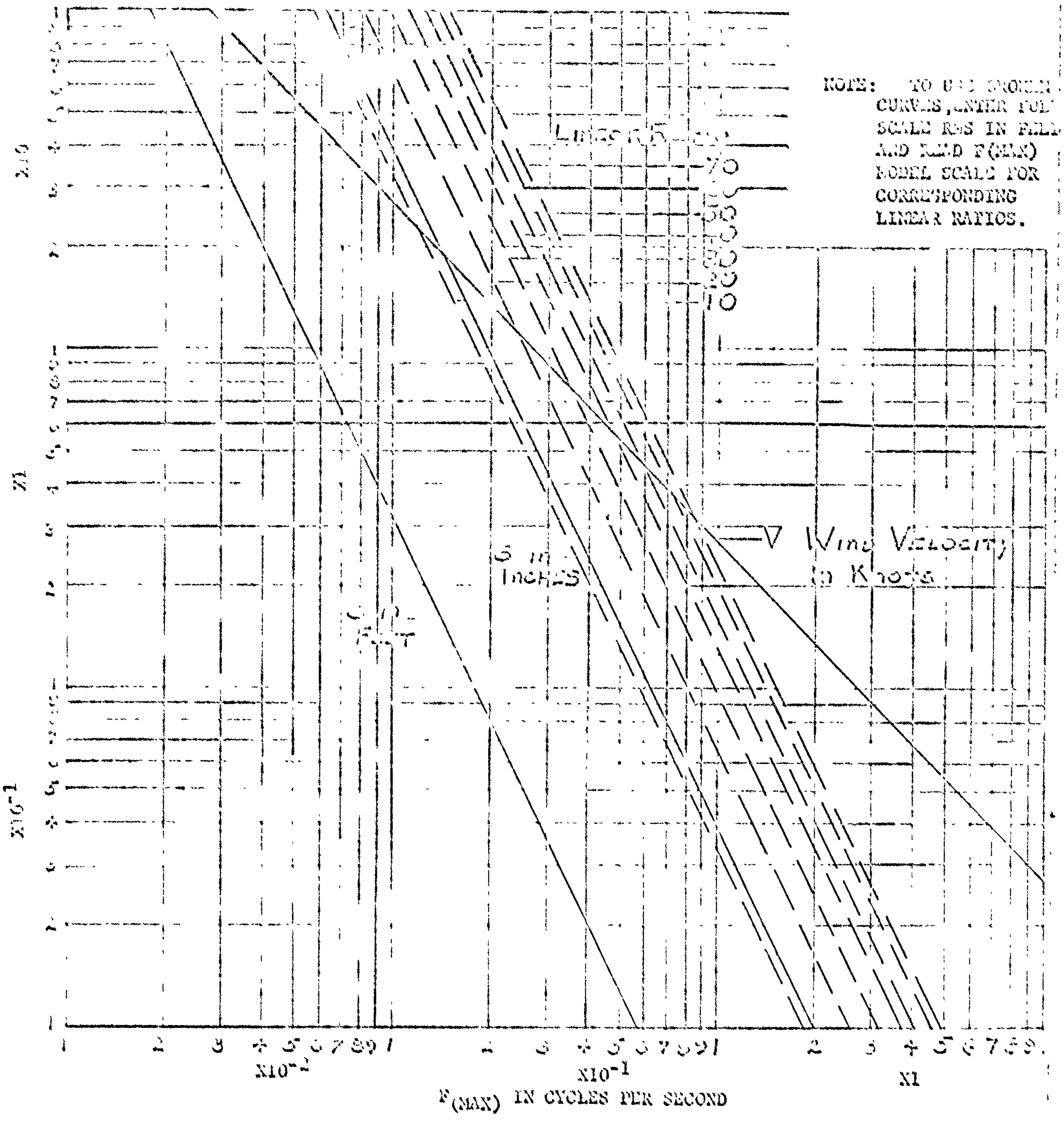


Figure 3 - RMS Verus Peak Frequency for Moskowitz Spectra.

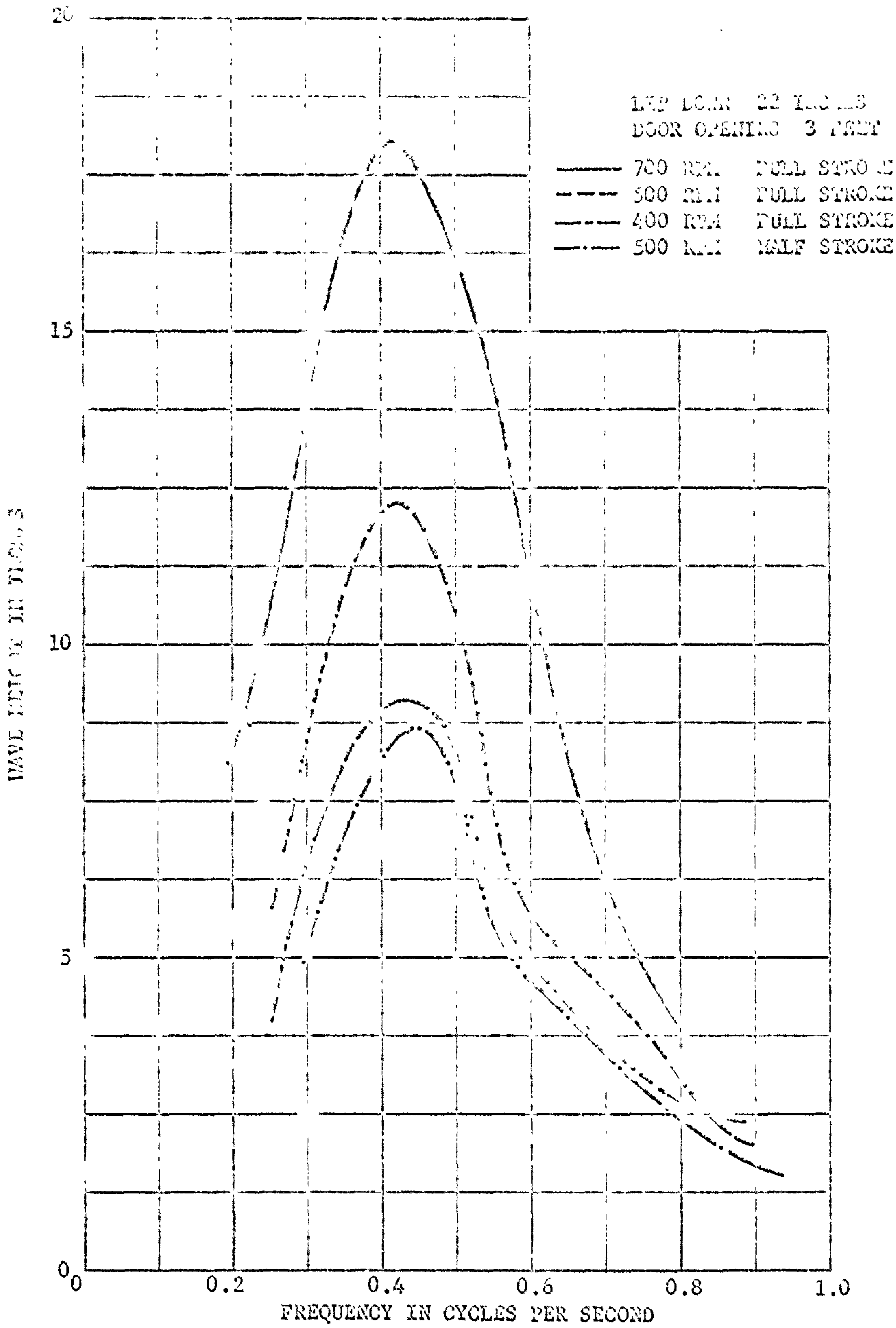


Figure 4 - Response Characteristics of Wavemaker - Lip Down.

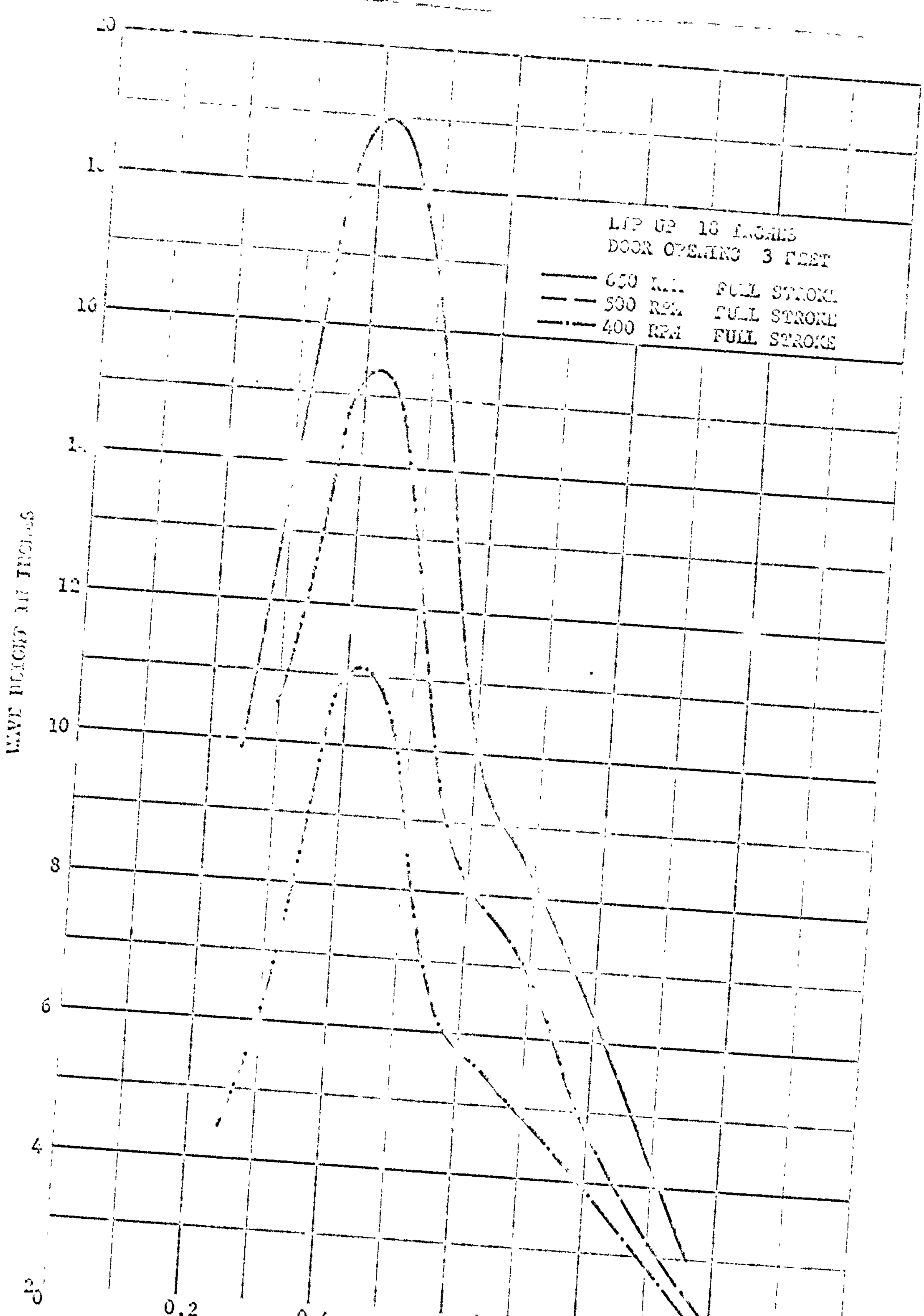


Figure 5 - Response Characteristics of Wavemaker - Lip Up.

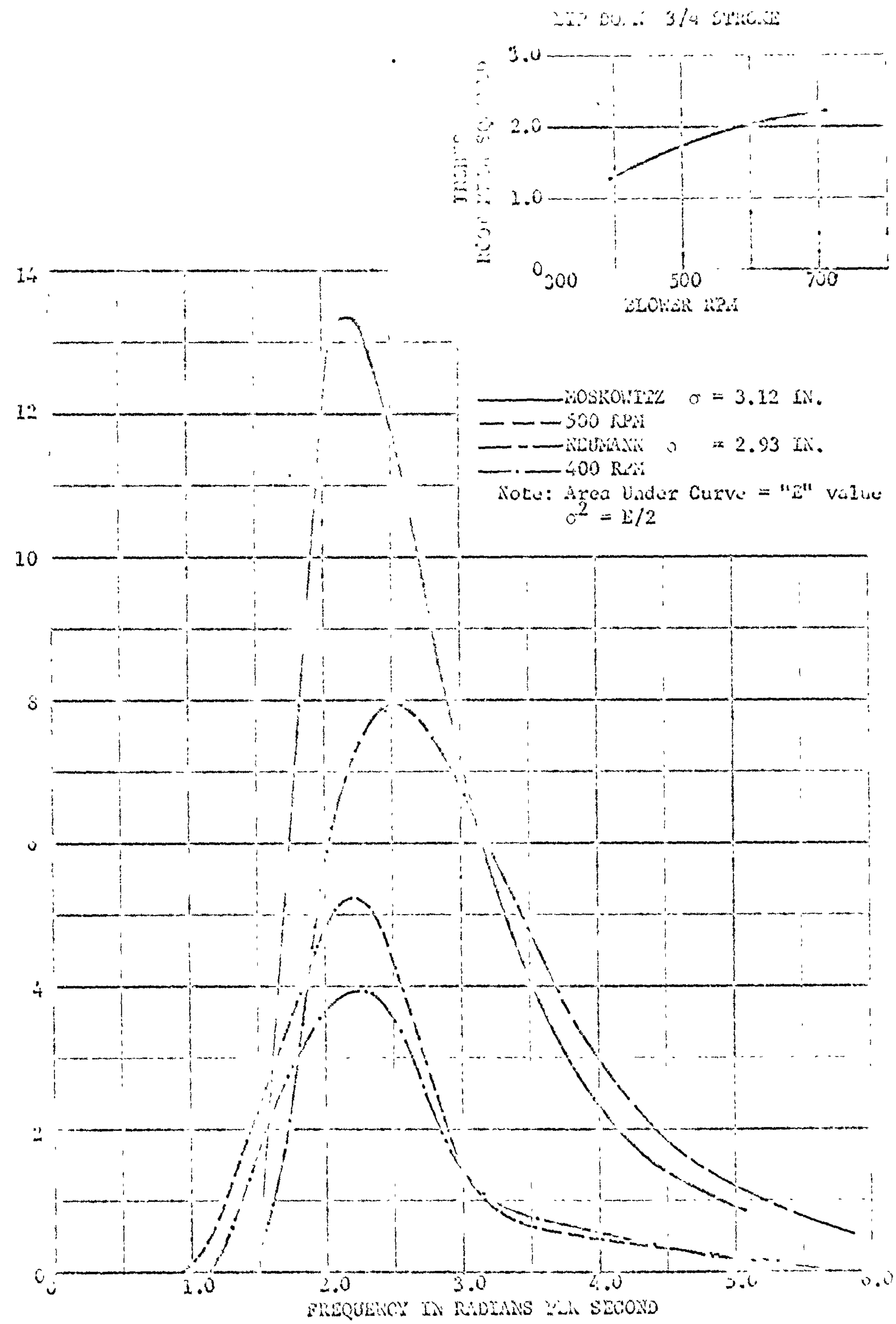
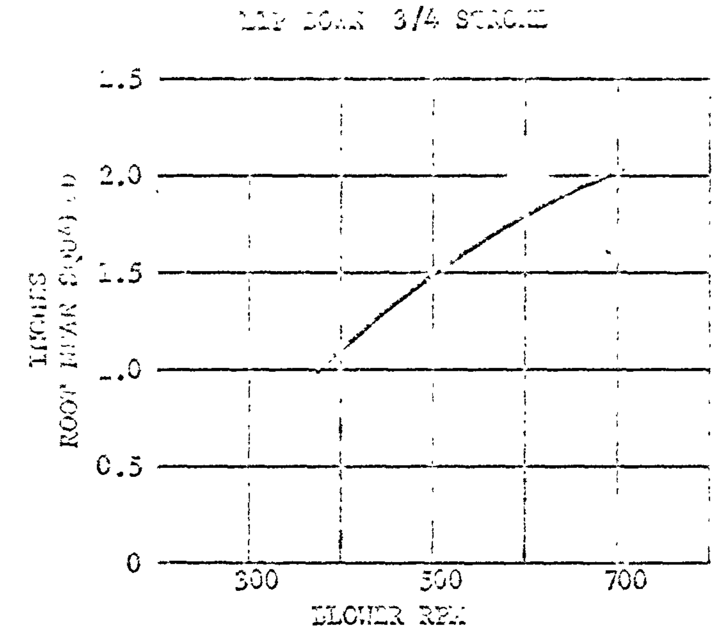


Figure 6 - Program 1 Wave Spectra for Several Blower RPM



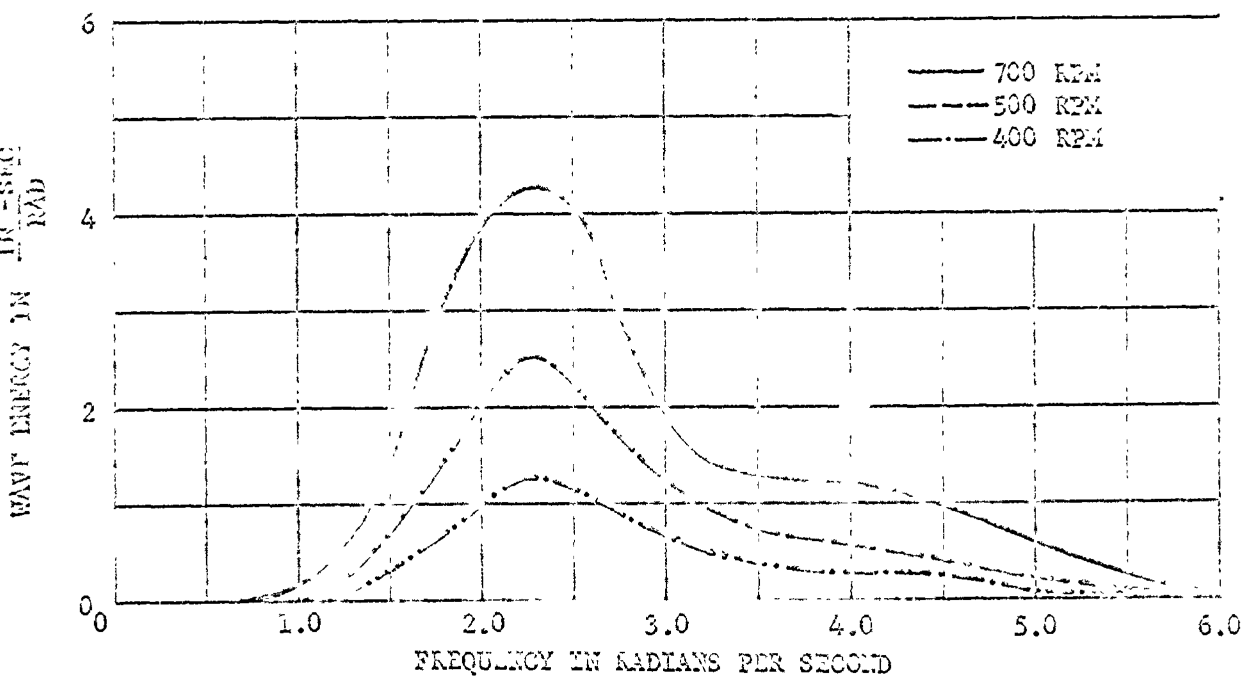
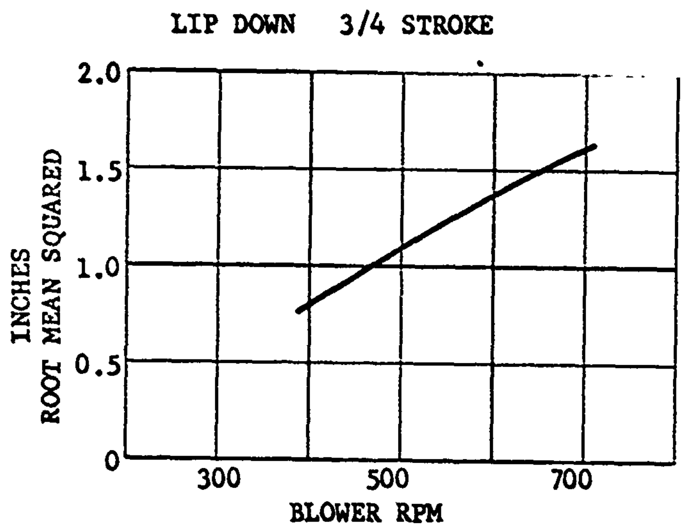


Figure 7 - Program 2 Wave Spectra for Several Blower RPM.



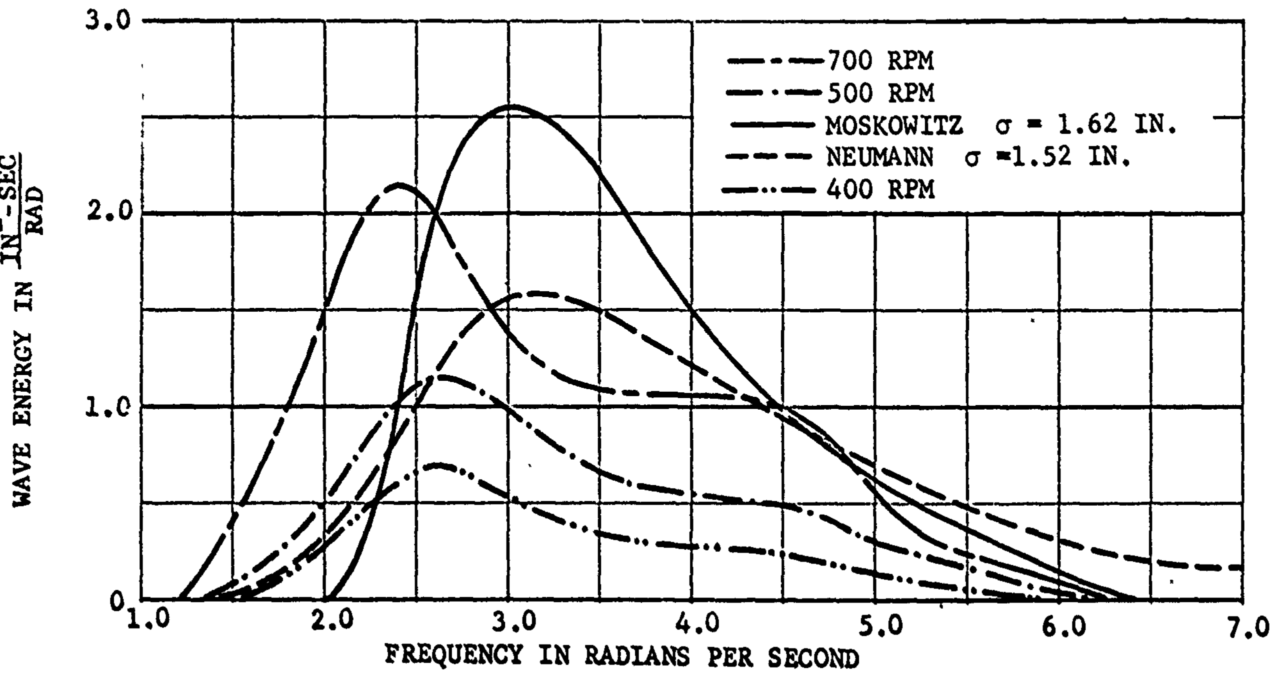


Figure 8 - Program 3 Wave Spectra for Several Blower RPM.

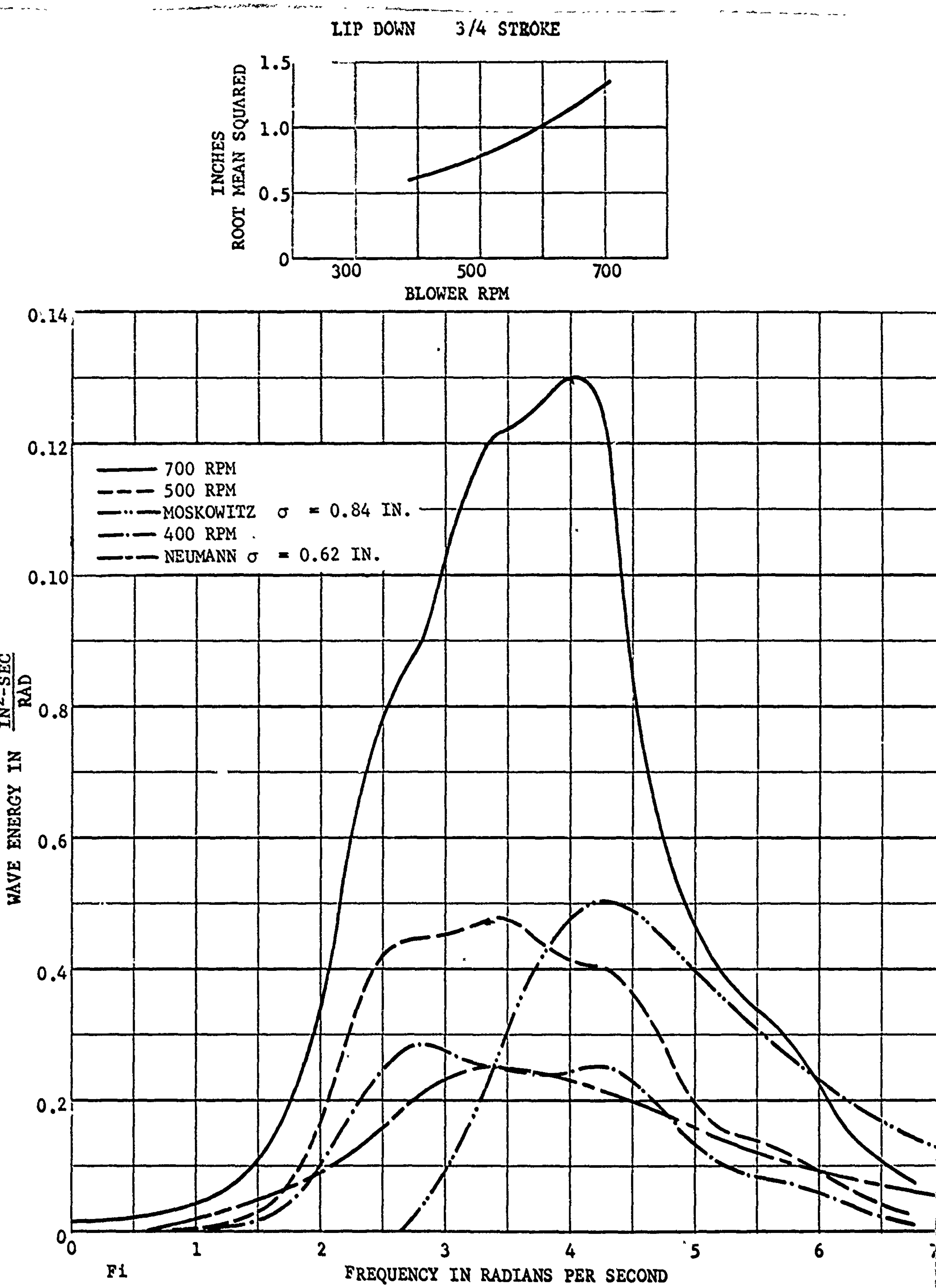


Figure 9 - Program 4 Wave Spectra for Several Blower RPM.

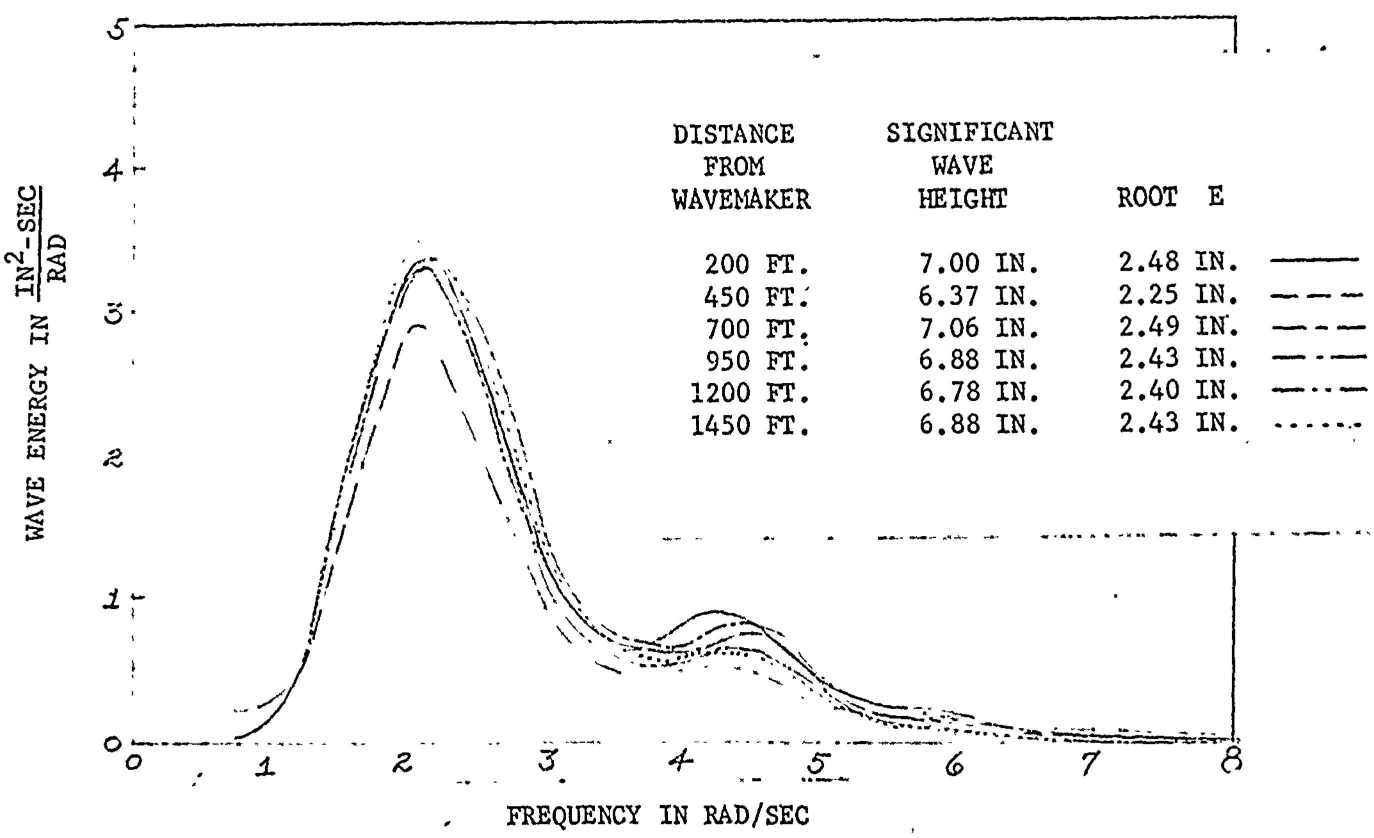


Figure 10 - Program 1 Wave Spectra Measured at Various Distances from the Wavemaker.

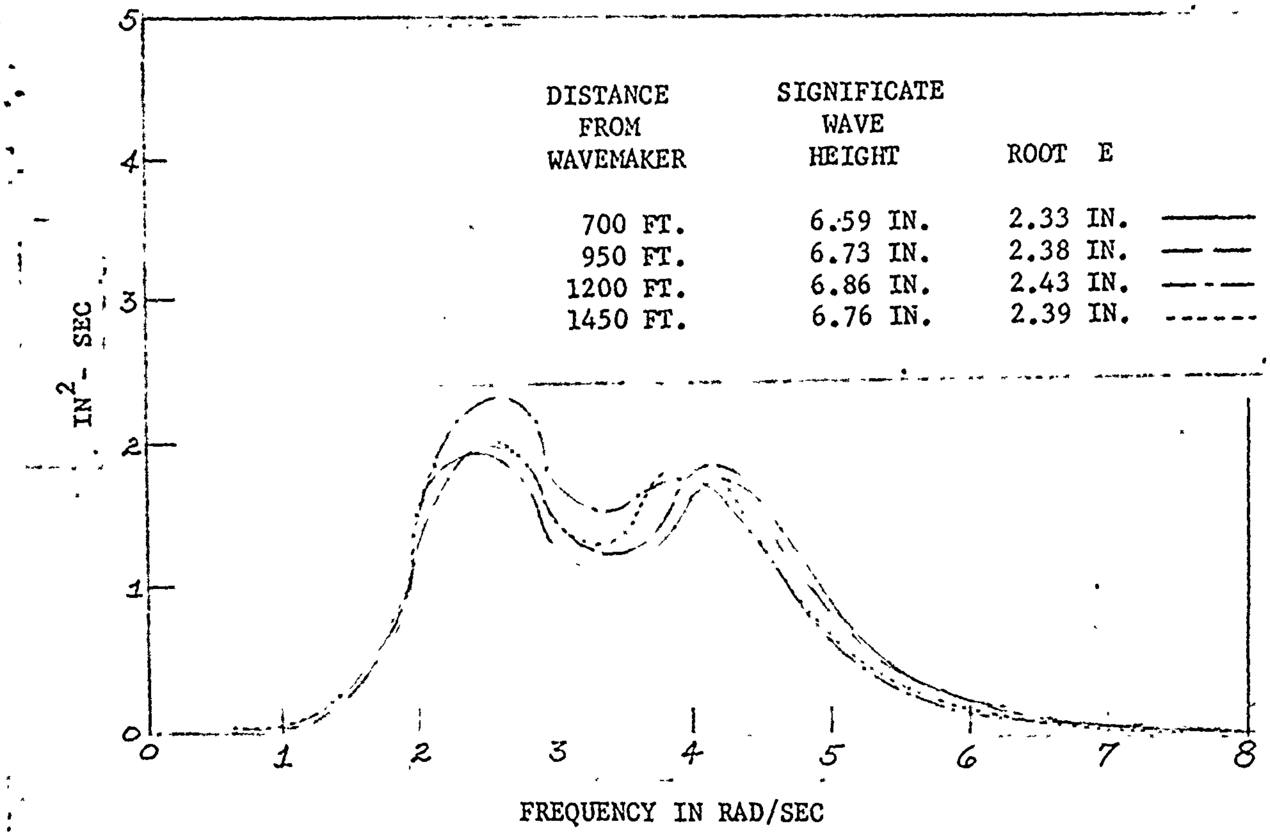


Figure 11 - Program 3 Wave Spectra Measured at Various Distances from the Wavemaker.

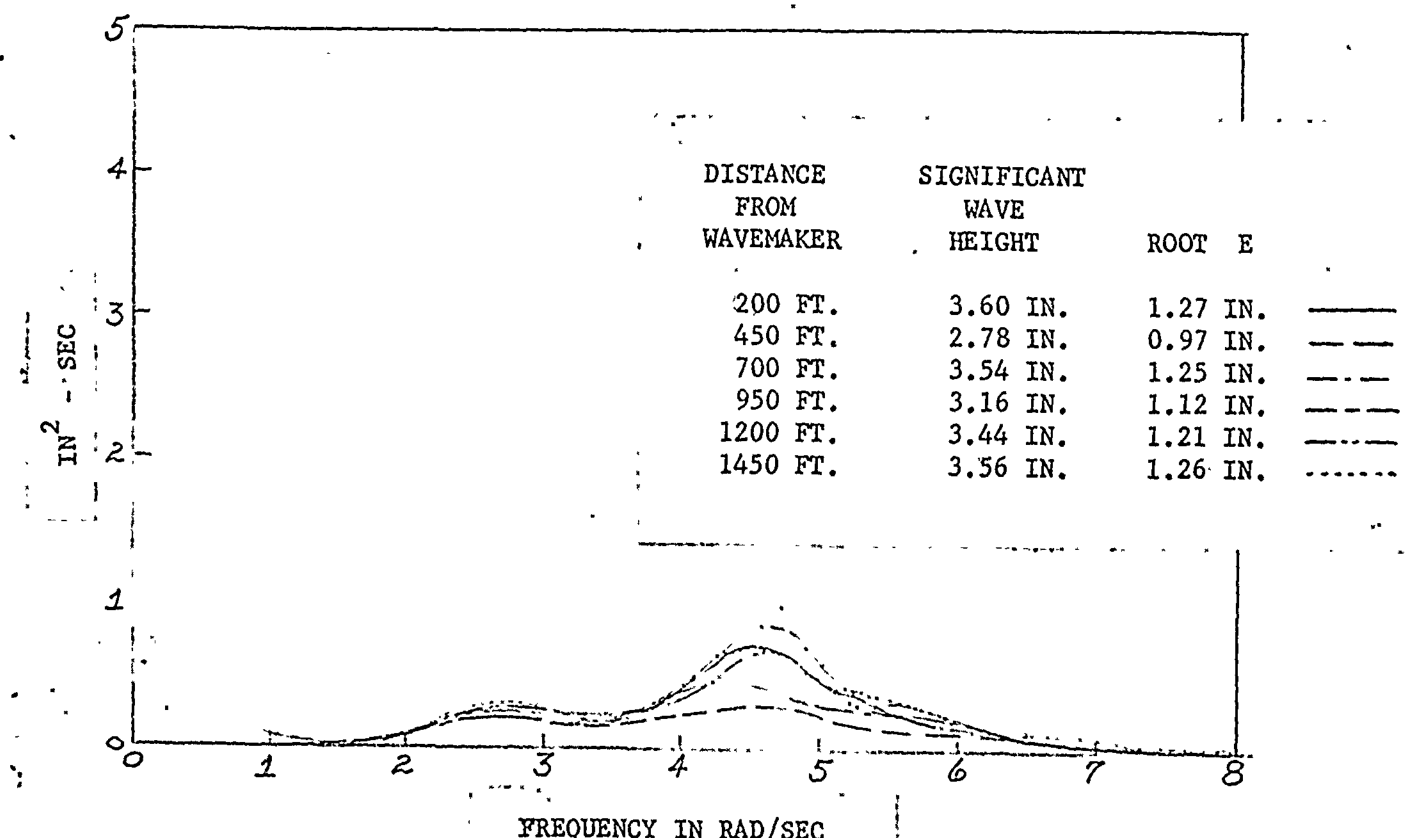


Figure 12 - Program 4 Wave Spectra Measured at Various Distances from the Wavemaker.

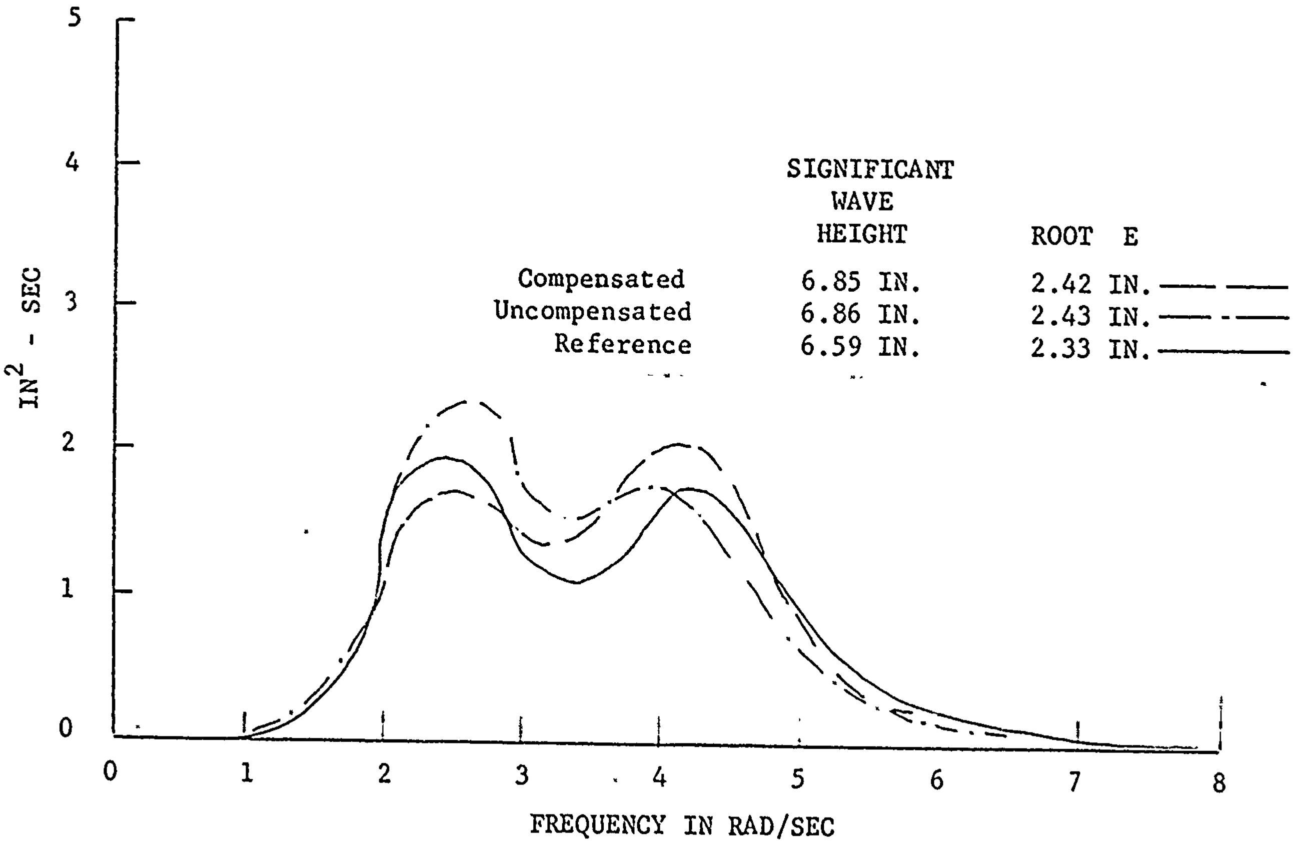


Figure 13 - Effects of Compensating initial Portion of Program for Differences in Propagation Velocities of the Various Wave Components.